NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a progress report at least every three months during the project duration. Reports are due the 5th of the month following the end of the quarter. Please provide a project update even if no work was done during this reporting period.

Project # 26962M	**Report Period** Year: 2017 ☐Q1 (Jan-Mar) XQ2 (Apr-Jun) ☐Q3 (Jul-Sep) ☐Q4 (Oct-Dec)	
Project Title: Evaluation of Gusset-less Truss Connection to Aid Bridge Inspection and Condition Assessment		
Project Investigator: Erin S. Bell Co-Project Investigator: Ricardo Medina **Phone: (603)862-3850** **E-mail: erin.bell@unh.edu**		
Research Start Date: December 15, 2016	**Research End Date:** December 31, 2018	**Project schedule status:** ☐ On schedule ☐ Ahead of schedule X Behind schedule

Brief Project Description:

The Memorial Bridge connecting Portsmouth, NH and Kittery, ME was re-opened to traffic in 2013. One of the major innovations of the reconstructed bridge is the first ever gusset-less truss connection in a vehicular bridge in the United States. Traditional gusset plates are the most vulnerable element in a truss-bridge structure and a source of significant cost, effort, and concern for bridge managers and owners. The goal of the proposed research is to integrate field-collected performance data, laboratory experimental testing, and physics-based structural modeling to develop a protocol to assess the condition and predict the remaining life of the gusset-less truss connections used at the Memorial Bridge. It is anticipated that the aforementioned approach will be modified to develop a framework to extend this protocol for application to future innovative structural elements.

The objectives of this project are to:

- Create two specimen pairs (A and B) of a scale model of a gusset-less connection from the Memorial Bridge. Specimen pair A (top chord connection) will be tested to failure in a quasi-static testing protocol and Specimen pair B (bottom chord connection) will be tested for fatigue performance.
- Conduct quasi-static set of tests on each member of Specimen pair A to determine stress distribution in the connection.
- Evaluate these results in conjunction with field collected data and analytical models that are the work product of a complimentary FHWA-AID DEMO project to: (i) further understand and quantify the structural performance of the gusset-less connection, and (ii) validate analytical models.
- Conduct fatigue testing on Specimen pair B and collect performance data to determine the stress pattern and predict fatigue failure mode.
- Compare the findings of this project with the FHWA guideline for connection assessment to facilitate the development of an evaluation protocol for inspection and structural condition assessment.

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):

Complete Literature Review and Finalize Testing Plan

This literature review and testing plan was started as part of PI Bell's graduate course in advanced steel design and has continued in the spring as part of co-PI Medina's experimental structural dynamics class. This literature review has included an evaluation of the summary calculations for the gusset-less connection provided by HNTB, which were made

available to the research team after the project proposal was submitted. A graduate student, Fernanda Fischer, completed a majority of this task by June 2017. Additional topics were added to the literature survey scope at the May 19th TAG meeting, including the impact of weld defects on the fatigue life of welded connections.

Design and Construction of Small-scale Physical Models

A plate buckling specimen was designed as part of the advanced steel graduate course in fall 2016. This specimen was fabricated in February 2017, the test of this specimen was behind schedule as the fatigue-rated actuator was delayed in being installed at the testing frame in the structural testing laboratory at the University of New Hampshire (UNH)..

Also based on the discussion at the May 19th TAG meeting, fatigue tests of weld specimens (coupons), with defects and without defects, were planned for Summer 2017. These tests are scheduled to be completed by the end of August 2017. It is hypothesized herein that based on the size of the fillet welds used along the bend radius of the gusset-less connection (5/8" thick) and a conservative design approach, it is unlikely for a weld to fail during the 75-years service life of the bridge unless a defect is present. Hence, the purpose of these tests is twofold: (1) to evaluate experimentally the influence of defects such as incomplete fusion, inadequate joint penetration, cracks, porosity, and slag inclusion on the expected fatigue life of welds; and (2) to use the knowledge gained from these experiments to inform the design of the bottom chord, gusset-less connection specimen to be used for fatigue testing as part of a subsequent task in this project. These weld specimens will be exposed to stress levels commensurate with the allowable stresses used in the design of the fillet welds along the bend radius of the gusset-less connection.

In this quarter, the weld specimens were designed and fabricated and fatigue testing with mock/dummy specimens has been completed using the Instron Universal Testing Machine at the Structural Engineering Laboratory at UNH. For testing purposes, groove V 45^{o} welds are used. The welds have material properties consistent with those used for the welds at the Memorial Bridge connections. The fabrication process involved the use of 5/8"-thick steel plates that were welded together by a certified welder with and without the use of a backing bar (see example in Figure 1) Various types of defects were induced along the length and depth of the weld, e.g., glass beads and shims were inserted at various locations to induce these defects. Then, the plates were cut transversely in order to obtain square (coupon) specimens, with the weld in the middle (Figure 2), that were then machined to produce specimens that were straight, with smooth faces, and with threaded ends to facilitate their attachment to the Universal Testing Machine (Figure 3). Attachments/adaptors had to be designed and fabricated to test the specimens. Based on the mock tests, additional changes need to be made to the attachments of the specimens to the Instron machine to eliminate undesirable bending and torsional stresses on the coupon specimens. Alternatively, the research team is exploring the possibility of testing using a Universal Testing Machine in the Department of Mechanical Engineering at UNH. The advantage of this machine is that it already has the required adaptors and attachments to conduct the fatigue tests and additional fabrication of attachments would be unnecessary.

Figure 1: 5/8”- thick steel plate with backing bar before welding

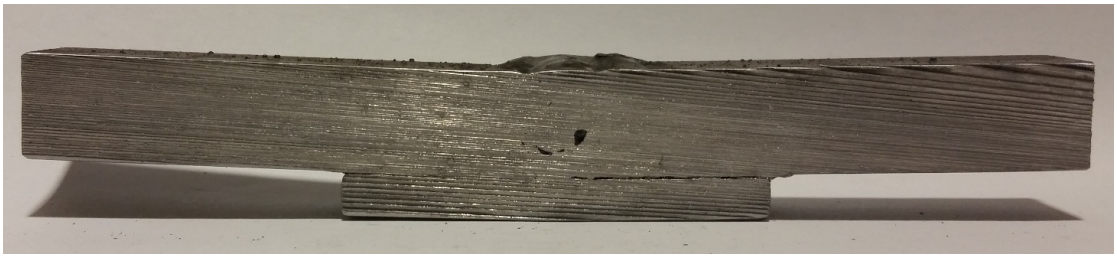

Figure 2: Example specimen cut with defective weld in the middle

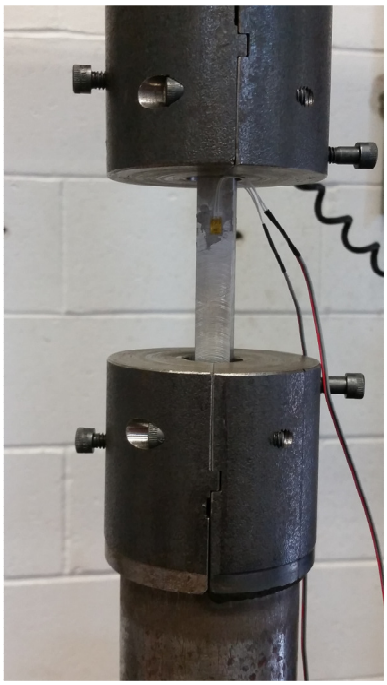

Figure 3: Mock specimen during test

Analytical Models of Small-scale Physical Specimens

Preliminary models for the gusset-less connection and plate buckling specimen were created as part of the advanced steel design course in fall 2016. These models will be calibrated with test data over the course of the first year of this project. After the first TAG meeting (March 28th 2017), the testing plan was modified to test the strength of the connection element not to failure. This will allow the use of larger physical specimens and will impact the design of the test setup. A decision was made to keep the bend radius constant at 16t, which is the bend radius used in the gusset-less Memorial Bridge connection, and test configurations with a different plate thickness, t, instead.

At the May 19th TAG meeting, the idea of testing half of the full-scale gussetless connection was presented by UNH and accepted by the NHDOT, provided that the boundary conditions were configured to mimic the stress distribution of the full connection, particularly in the immediate area adjacent to the fillet weld section exposed to the highest stresses (Figure 4). The associated models were created for this test design and the boundary conditions for the experimental setup are under design.

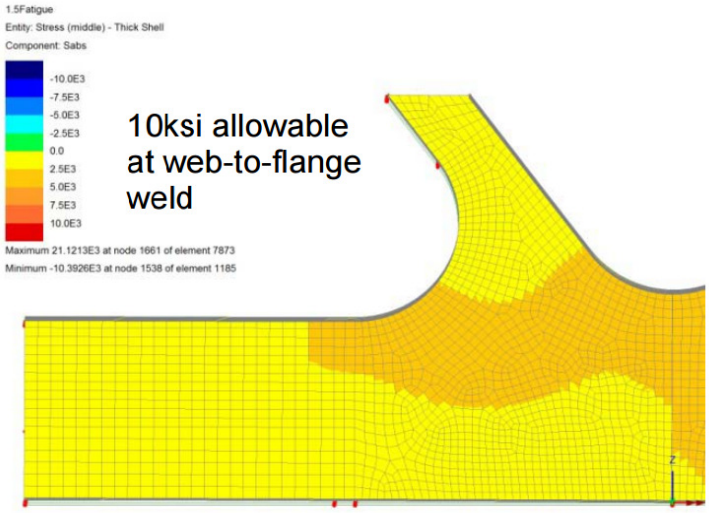

Figure 4: Fatigue stress distribution from HNTB design calculation

Quasi-Static Testing
An initial evaluation of testing alternatives to conduct the quasi-static test was performed using the loads obtained from the HNTB summary calculations. The main testing limitations relate to the capacity of the fatigue-rated actuator at UNH (110 kips) and the configuration of the existing testing frame (to support the actuator). Preliminary calculations and drawings for the test set up were presented in the first TAG meeting (March 28th 2017). During the meeting, a decision was made not to test physical models of a connection at the top chord to failure, for the bridge was designed to experience buckling failure of the diagonals before buckling of the connection panel zone region were to occur.

The load test of the Memorial Bridge was discussed at the May 19th TAG meeting. Additional scenarios were added to the load test plan to collect data related to the fatigue performance of the fracture-critical connection at the Memorial Bridge. The structural health monitoring system at the Memorial Bridge, installed as part of the Living Bridge Project, is fully operational and is collecting structural response data to determine the structural parameters and in-service performance of the gussetless truss connection.

Validation of Structural Connection Analytical Model
There was no progress on this task during this reporting period.

Fatigue Testing
An evaluation of the summary design calculations produced by HNTB, which include results from finite element analysis of gusset-less connections at the lower chord, was conducted to identify expected critical areas of stress concentration for fatigue analysis and testing. The calculations were helpful to identify trial design configurations that would be useful to finalize the geometry of the specimen pairs B. A discussion ensued in the March 28th TAG meeting on the possibility of adding test on the weld alone and/or on single bent plates.

As discussed at the May 19th TAG meeting, fatigue tests of intact and defective welds in presently underway.
In order to test the gussetless connection of a typical bottom chord for fatigue loading, a model based on the original configuration of the connection was developed with the challenge of creating similar stress contours for fatigue loading, especially around the fillet weld section with the highest stresses, using only the UNH 110-kip actuator. The objective herein is not to have an identical representation of the connection, but instead, a test specimen with a bend radius of 16t in which the stresses in the fillet weld along the radius are consistent with those present in the prototype connection. Thus, the objective is to mimic the response of the critical region of the fillet weld locally even if away from this region the geometry, loading, and boundary conditions of the connection are not identical to those of the prototype. This goal was achieved by modeling half of the connection, by taking advantage of symmetry, and applying a tensile force at the bottom chord beam with an eccentricity from the centroid of the cross section with appropriate boundaries conditions (Figure 5).

The next step is to define the correct scale of the connection and design the test set up.

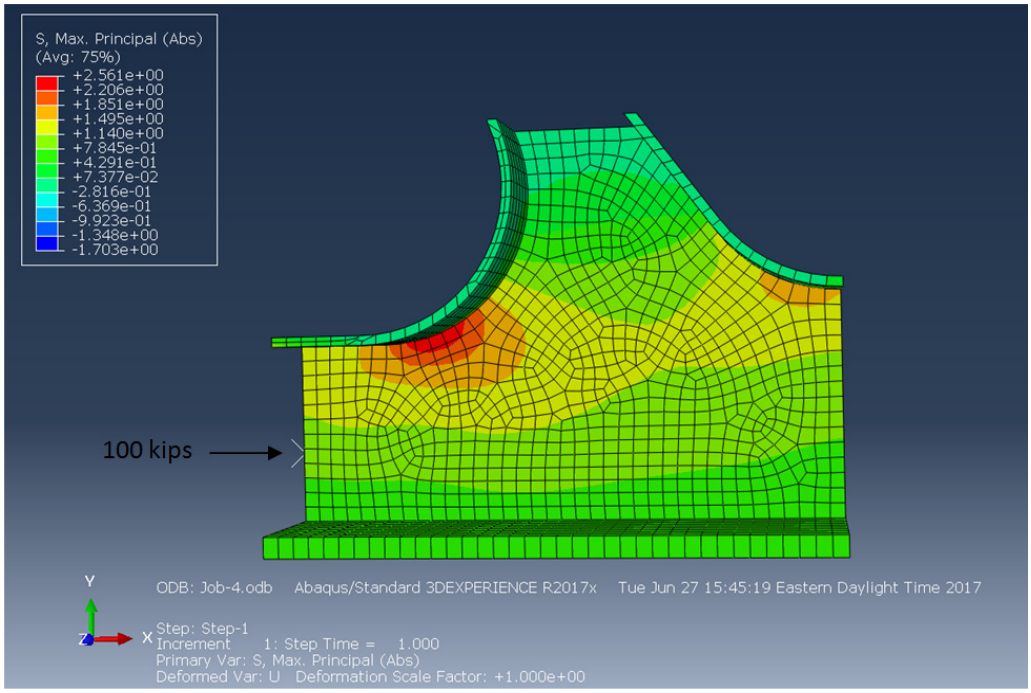

Figure 5: Half-connection model in Abaqus

Data Analysis and Interpretation of Laboratory Testing
There was no progress on this task during this reporting period.

Evaluation Protocol for Inspection and Condition Assessment
There was no progress on this task during this reporting period.

Final Report and Presentation
There was no progress on this task during this reporting period.

Items needed from NHDOT (i.e., Concurrence, Sub-contract, Assignments, Samples, Testing, etc):

There are no items needed from the NHDOT at this time. The research team is planning for the load test and will need the support of the NHDOT for this load test.

The research team would like to request a TAG meeting to review the testing plan in August 2017.

Anticipated research next 3 months:

Complete literature review.

Test the plate buckling specimens for model verification and calibration.

Complete the fatigue testing of weld samples – intact and defective and identify the appropriate defect inform the design of the bottom chord, gusset-less connection specimen to be used for subsequent fatigue testing.

Use field data for the strain gauges installed at the Memorial Bridge for final calibration of numerical models of the bridge.

Complete the design of test specimens and setup for both quasi-static and fatigue testing.

Coordinate with CANAM Bridge for specimen fabrication.

NHDOT SPR2 PROGRAM

RESEARCH PROGRESS REPORT

Circumstances affecting project: Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and budget, along with recommended solutions to those problems.

As described in the "Progress this Quarter" section of this report, the schedule delay and increased cost related to the electrical conduit negatively impact this project.

Tasks (from Work Plan)	Planned % Complete	Actual % Complete
Evaluation of Gusset-less Truss Connection to Aid Bridge Inspection and Condition Assessment		
Literature Review and Finalize Testing Plan	**100**	**75**
Design and Construction of Small-scale Physical Models	**75**	**50**
Quasi-Static Testing to Failure	**0**	**0**
Validation of Structural Connection Analytical Model	**0**	**0**
Fatigue Testing	**50**	**10**
Data Analysis and Interpretation of Laboratory Testing	**0**	**0**
Evaluation Protocol for Inspection and Condition Assessment	**0**	**0**
Final Report and Poster	**0**	**0**